SPECIAL REPORT RDMR-AE-17-02

STUDY OF ARMY DESIGN HOVER CRITERIA

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September 2017

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 074-0188
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1. AGENCY USE ONLY	2. REPORT DATE September 2017	3. REPORT TYPE AND DATES COVERED Final, October 2004 – October 2005	
4. TITLE AND SUBTITLE Study of Army Design Hover Criteria			5. FUNDING NUMBERS
6. AUTHOR(S) Douglas V. Horacek and Mark E. Calvert			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Commander, U.S. Army Research, Development, and Engineering Command ATTN: RDMR-AE Redstone Arsenal, AL 35898-5000			8. PERFORMING ORGANIZATION REPORT NUMBER SR-RDMR-AE-17-02
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING / MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES Presented at the 2005 Huntsville Simulation Conference, Huntsville, AL, 25 – 27 October 2005			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE A
13. ABSTRACT *(Maximum 200 Words)* What altitude and temperature combination should be specified as a design point to ensure world-wide vertical flight capability for U.S. Army helicopters? This question was answered in 1970 by Robert Bellaire and Lieutenant William Bousman for the development of the Army's 2nd generation of helicopters (1970-1981). An update of the 1970 study is in progress. This update includes recent climatological and terrain data collected and processed by the use of the U.S.A.F. climatological model to represent areas between stations for a specific area. Regions of the world included in the 1970 study, as well as new relevant world regions are included in the new study.			
14. SUBJECT TERMS military, aerospace, transportation			15. NUMBER OF PAGES 12
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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ABSTRACT

What altitude and temperature combination should be specified as a design point to ensure world-wide vertical flight capability for U.S. Army helicopters? This question was answered in 1970 by Robert Bellaire and Lieutenant William Bousman for the development of the Army's 2nd generation of helicopters (1970-1981). An update of the 1970 study is in progress. This update includes recent climatological and terrain data collected and processed by the use of the U.S.A.F. climatological model to represent areas between stations for a specific area. Regions of the world included in the 1970 study, as well as new relevant world regions are included in the new study.

INTRODUCTION

The U.S. Air Force Combat Climatology Center in Ashville, North Carolina, is home to the Advanced Climate Modeling and Environmental Simulations (ACMES) that models the atmospheric conditions anywhere in the world. The present model estimates temperatures and elevations on a 40 kilometer grid then interpolates the temperature data to a 10 kilometer grid, the 10 kilometer elevation is determined from 1 kilometer grid accuracy of satellite data. A table of the monthly daily maximum, daily mean, and daily minimum temperatures with elevations for the 10 kilometer grid and is used to display an isopleth chart of constant temperature for the cumulative probability of altitude and cumulative probability of temperature. The range for these charts is a wider range of temperatures and altitudes than reported in the Bousman Report (Bellaire and Bousman 1970) which was published in 1970. A helicopter Hover Out of Ground Effect (HOGE) curve is placed across this chart, and the area under the curve is an evaluation of a Stieltjes Integral that is also the probability of hover for a given country.

Maps can be generated where the aircraft can hover or not. The probabilities of hover tend to be lower than those calculated with the Bousman data, thus placing more constraints on the design points discussed in the Bousman Report (Bellaire and Bousman 1970). The purpose of this report is to discuss the newly available climatology data and these recently developed methods of estimating the probability of hover and availability of graphics software to present the results and how the results affect design points.

DESIGN POINT

The two most significant atmospheric conditions affecting rotorcraft performance are pressure and temperature. The density of air is proportional to pressure and inversely proportional to temperature. Compressibility effects are inversely proportional to the square root of the temperature of ambient air. Both compressibility and air density determine the amount of work that a rotor has to accomplish in order to propel a rotorcraft. Thus, the choice of a unique pressure and temperature design point for use in the design of a rotorcraft ultimately decides its capability.

It is known that hydrostatic pressure in a gas decreases with increasing elevation. The temperature variation with altitude has been standardized by analysis of data gathered from atmospheric studies. Using the hydrostatic behavior of air, and the temperature variation with altitude, it is possible to define atmospheric pressure by the corresponding altitude according to the standardized atmosphere model. Thus, the atmospheric pressure for a given terrain may be correlated to its elevation, allowing rotorcraft design to be guided by the intended area of operation.

In the mid-1950's the United States Army promulgated a requirement that future Army helicopters should be capable of hover out of ground effect at a pressure altitude of 6,000 feet and an ambient temperature of 95 degrees Fahrenheit (6K/95). This combination of temperature and pressure altitude, called the Standard Hot Day, was judged as being representative of limiting atmospheric conditions in areas of possible future military operations.

At the onset of the program to develop the Utility Tactical Transport Aircraft System (Black Hawk) in 1966, the United States Army Combat Developments Command (USACDC) contracted a study to develop a new Hot Day Standard design point based upon the climatology of regions within Soviet-Sino influence. This investigation parametrically coupled helicopter design to the probability of occurrence of terrain elevation and mean daily temperature. The desired goal of this effort was to generate a unique design point that could be applied to future aircraft acquisition and development in order to optimize worldwide strategic capability with respect to total life cycle cost. Based upon a parametric analysis of helicopter capability at various altitudes at 95 degrees Fahrenheit, a design point of 4,000 feet pressure altitude and 95 degrees Fahrenheit (4K/95) was recommended as the HOGE capability requirement. This design point was expected to provide a ninety-five percent probability of HOGE in the regions studied.

The 4K/95 HOGE design point became controversial due to its neglect of diurnal temperature variation and aircraft performance losses due to weight gain and mechanical degradation. In 1968, USACDC conducted another study, which recommended a 500 feet per minute vertical rate of climb (VROC) capability with 5 percent power margin at 4,000 feet pressure altitude and 95 degree Fahrenheit ambient temperature design point. This recommendation did not account for diurnal temperature variation, however.

In 1975, the Advanced Scout Helicopter Special Study Group reexamined the design point requirement. They recommended increasing the design point pressure altitude requirement to 6,000 feet while maintaining the 500 feet per minute VROC with 5 percent power margin capability to account for realistic helicopter operating conditions. However, the design point remained at 4K/95 for development and modernization of rotorcraft for the next three decades. Recently, there has been renewed interest in increasing the design point to 6K/95 due to experience gained in military operations in Southwest Asia.

CLIMATOLOGY MODEL

To find the probability of hover we evaluate the following Stieltjes Integral:

$$P(H) = \int_{-\infty}^{\infty} P(T \leq f(y) \big| H_p = y) dP(H_p \leq y)$$

This can be done by plotting a HOGE curve across an isotherm plot that is cumulative probability of temperature on the x axis versus the cumulative probability of altitude on the y axis. The area under the curve on this plot is the value of the Stieltjes Integral for the probability of hover. In the 1970s this area was estimated by a planimeter. Today we fit a curve through the HOGE data and from the fitted curve we can tell which of the original data points are above or below the curve, we add up the ones below the curve and divide by the total number of points to get the probability of hover for a particular country or state or province world wide.

Figures 1 through 6 demonstrate the isotherm charts and the HOGE for the mean daily maximum temperature, the mean daily average and the mean daily minimum temperature. Notice the mean daily minimum temperature has the most area under the HOGE curve; hence, flying at night gives improved hover capability. This is demonstrated in Figure 17 where the Maximum Probability is due to the minimum temperature. The Minimum Probability is due to maximum temperature and the Average Probability is due to the average temperature.

The monthly and seasonal variations in the probability of hover are shown in Figures 15 and 16 respectively. The Maximum Probability is due to the minimum temperature the Minimum Probability is due to the maximum temperature and the Average Probability is due to the average temperature. There is more hover capability in the winter months when the weather is cooler.

Thus night time and the winter months are more suitable for helicopters to hover than day time and summer months which tend to restrict more tightly the possibility of hover.

In addition to these graphics maps of California, both two dimensional and three dimensional maps have been provided. In the presentation a video of the monthly variation in hover capability will be presented. The maps show where it safe to hover, limited hover capability due to the minimum temperature and no hover capability.

Each map showing the hover capability is compared to a map provided by the Air Force Combat Climatology Center in Ashville North Carolina. These maps provide the temperature variation and some idea of the altitude of the terrain. The three dimensional map also shows the altitude of the terrain and where it is safe to hover or not.

There is one two dimensional map for January and one for July and they are compared to the Air Force maps. There is also one three dimensional map for January and one for July that are also compared to Air Force maps.

These are shown in Figures 7 through 14. Notice there is no hover capability in the warm higher elevations of California, especially in the eastern mountain range which is the Sierra Nevada Mountains. The cooler mountains to the north and low lands of central California have unlimited hover capability.

Thus ideal hovering conditions are at night or in the winter in cooler regions with lower elevations. In January most of California has hover capability.

CONCLUSION

The ranges of the data are greater for the temperature and elevation or pressure altitude; therefore, it is more difficult to hover than the areas found in the Bousman Report. This may lead to desire a stronger design point than even 6000/95 for future aircraft if it is desired to operate with a higher percentage in difficult parts of the world. Thus the Air Force Data show flight is more difficult in certain parts of the world than the Bousman Data.

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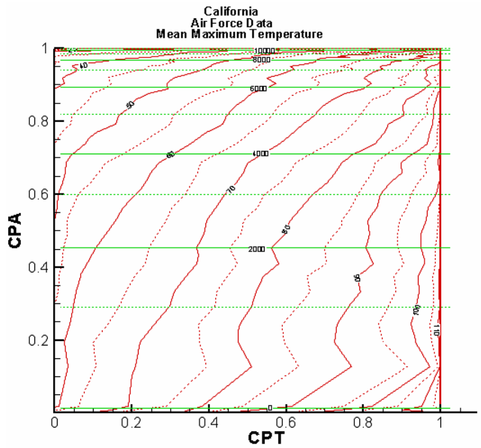
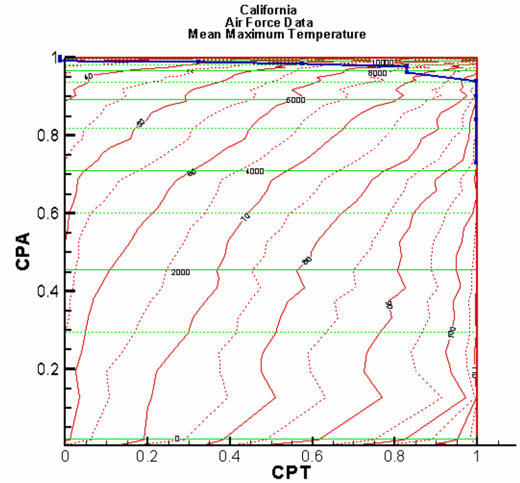


Figure 1.



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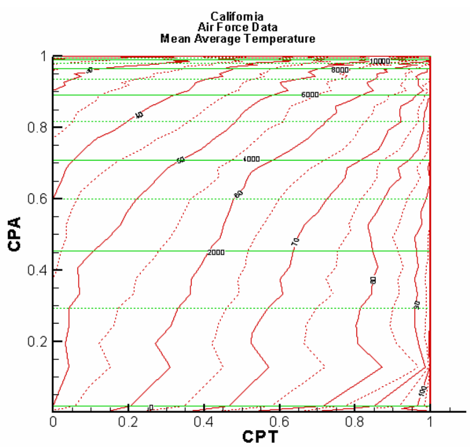

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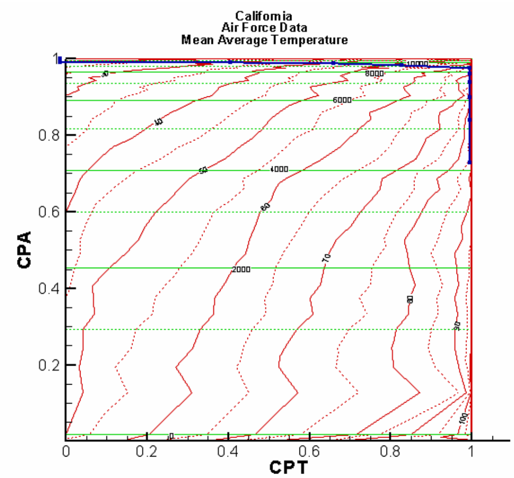

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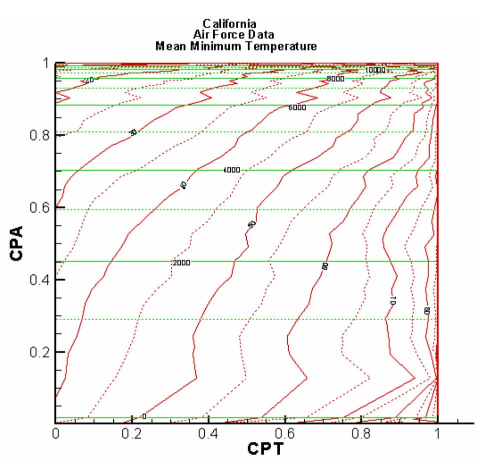

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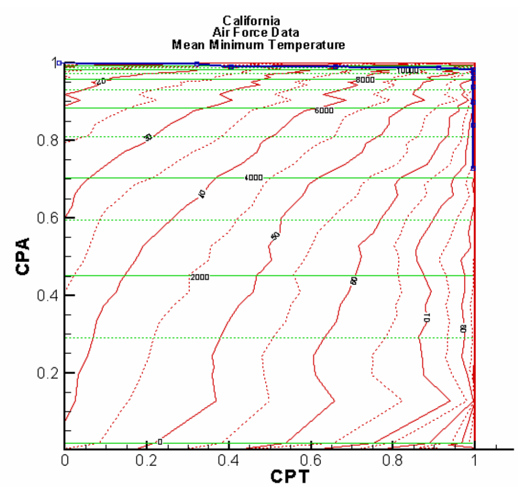

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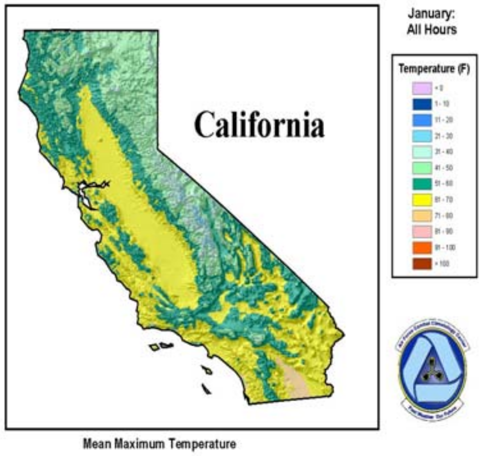

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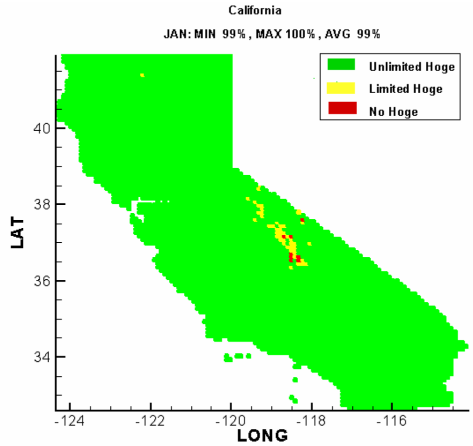

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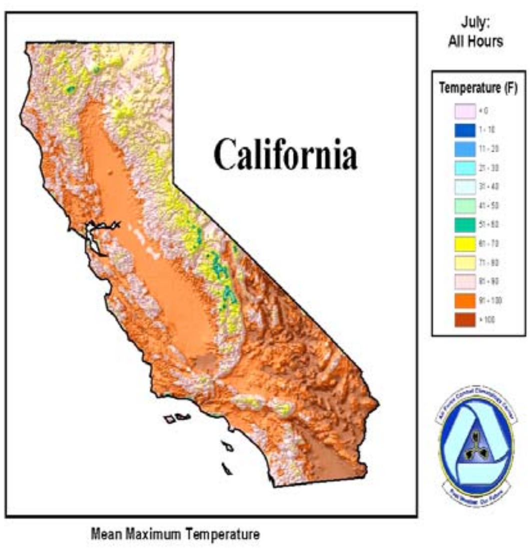

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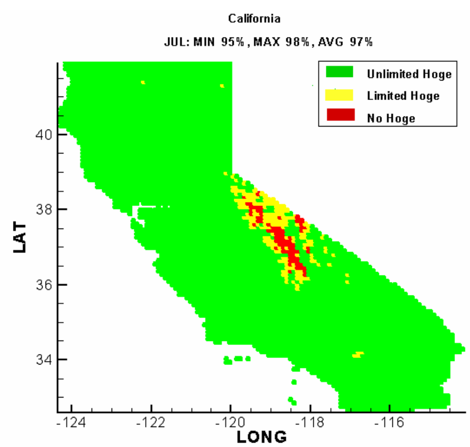

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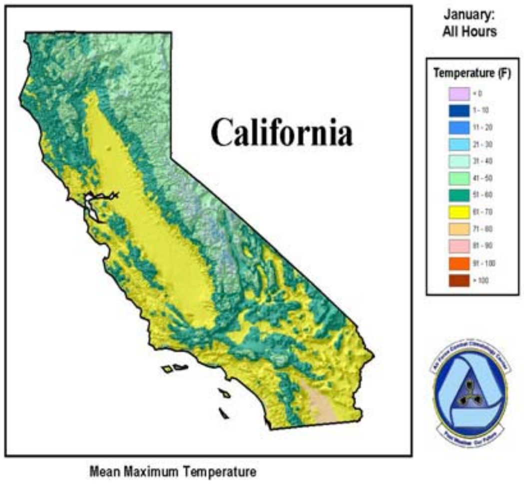

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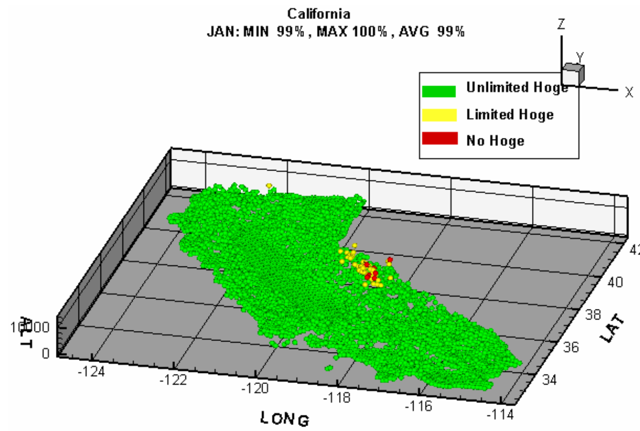

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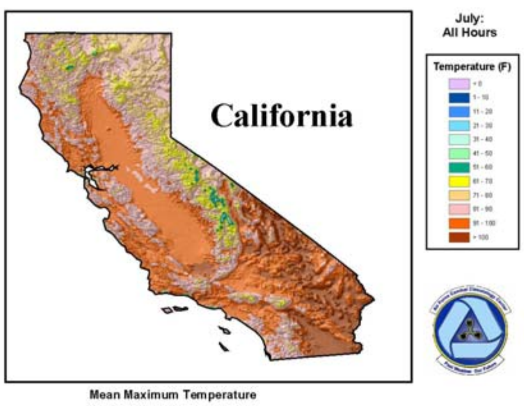

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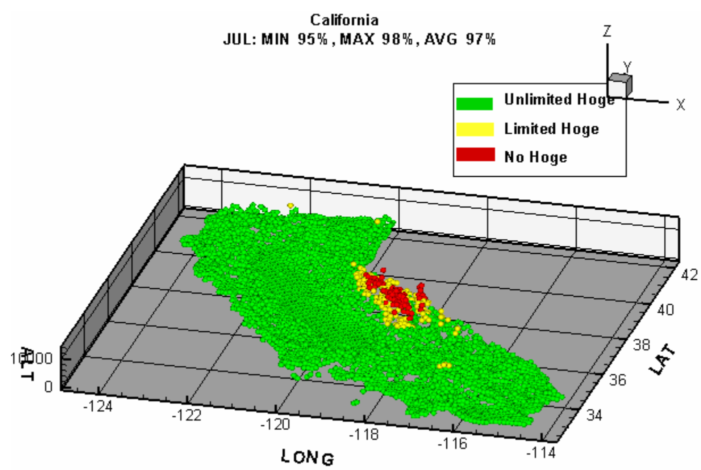

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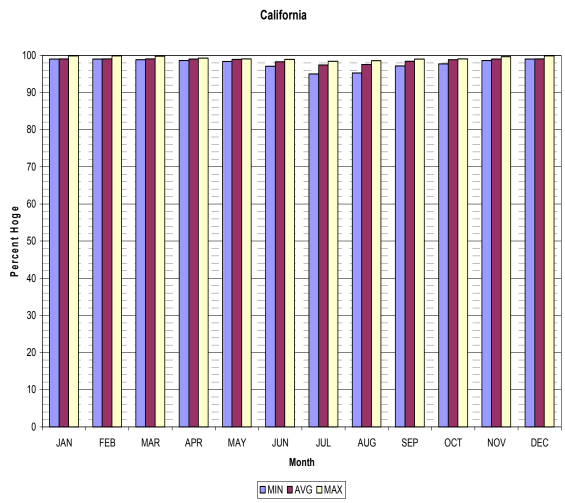

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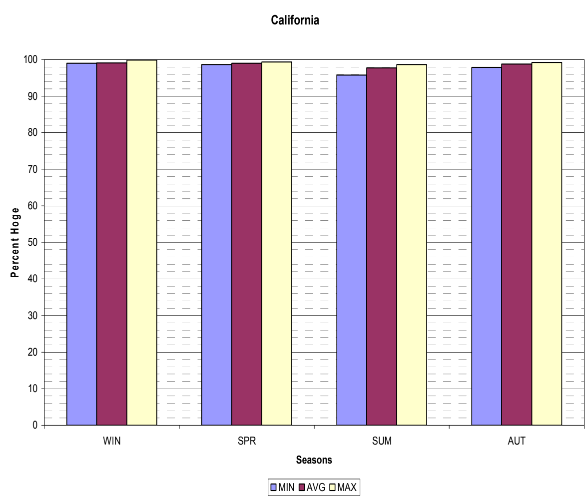

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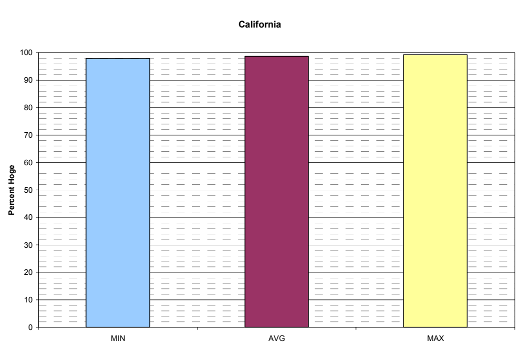

Figure 17.

BIOGRAPHIES

Douglas V. Horacek

Currently serves as an Operations Research Analyst for the U.S. Army Aviation and Missile Command. Uses U.S. Air Force Climatology Data to determine Hover Capability and where Helicopters Hover. Has a Bachelor of Science Degree in Applied Mathematics with an Area of Concentration in Physics from the University of Nebraska at Omaha in December of 1986 with some graduate work at Washington University in St. Louis Missouri and University of Alabama at Huntsville. Currently is a member of the American Physics Society. In October of 1992 received a Special Act Award and the Civilian Service Medal for a paper on the Hurst Ratio.

Mark E. Calvert

Mark Calvert is an aerospace engineer on the Rotors and Aerodynamics Team of the Aeromechanics Division in the Aviation Engineering Directorate of the U. S. Army Aviation and Missile Research, Development and Engineering Center at Redstone Arsenal in Huntsville, Alabama. He received a Doctorate of Philosophy in Mechanical Engineering from the University of Alabama in Tuscaloosa, Alabama in 2002.

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